The relation of Ohio bog vegetation to the chemical nature of peat soils*

ALFRED DACHNOWSKI

The ecological relation of plants to soils, particularly to the chemical nature of the substratum, is especially interesting and has been extensively studied from the standpoint of the distribution of species, the succession of vegetation, and the adaptability of crops to certain soils. In mountainous countries and even in states like Ohio, with soils of morainal and of varied geognostic nature, one can observe sharply delimited distinctions in the distribution and in the whole appearance of vegetation units. And yet, though many species are confined to soils with a definite chemical relationship, a great many plants can grow on soils widely dissimilar in kind. Are the reasons for the generally observed distinctions to be sought in the chemical constitution of the soil, or is the distributional relationship due to the physical characters, particularly to relations prevailing in regard to the amount of available water and the specific quantity required by the plants, and to the thermal condition in the soil?

Not all field work is adapted to throw light on this vexed question of a long standing dispute. Difficult as is the attempt to establish a correlation between vegetation and any one factor of the environment, it is possible, however, to make such a correlation with peat soils, within the area here investigated.

It is now generally recognized that the nature of a lake and bog environment is constantly selective, and that the associations and societies of plants succeeding one another are each characterized by a definite physiognomy in response to their dependence upon soil conditions under atmospheric influences essentially similar otherwise. In an earlier paper the writer has listed the successions of the more genetically related vegetation units, their associations and societies, occurring in Ohio lakes and peat deposits (Plant World **15**: 25–39. 1912).

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In connection with the problem of the utilization of Ohio peat, both chemical and calorimetric analyses were made of the peat samples collected. With the exception of the potash, phosphoric acid, and lime analyses, and the analyses of TABLES II and III, all determinations were made under the auspices of the United States Bureau of Mines as a part of more general investigations of the fuels of the United States. This cooperative work between the State and the Federal Government has been made possible through the considerate and helpful interest of Dr. Charles A. Davis, in charge of the peat investigations of the U. S. Bureau of Mines.

The analyses, as might be expected, vary widely, but there is a certain uniformity in regard to their chemical character. The analyses show the following range in chemical composition:

TABLE I

CHEMICAL ANALYSES OF OHIO PEAT. RANGE OF CHEMICAL COMPOSITION

	Minimum	Maximum
Volatile combustible	50.99	74.79
Fixed carbon	16.56	33.64
Ash	3.65	25.44
Nitrogen	1.01	3.68
Potash (K_2O)	0.10	0.98
Phosphoric acid (P_2O_5)	0.03	0.50
Lime (CaO)	0.00	4.52
Thermal value: calories,	3,962.00	5,409.00

Through the courtesy of Professor J. W. Ames of the Wooster (Ohio) Experiment Station a more detailed analysis of the ash of peat soil is here appended in TABLE II.

TABLE II

ANALYSES OF PEAT SOILS, CHEMICAL DEPARTMENT, OHIO AGR. EXP. STATION
TOTAL AMOUNTS FOUND

Lab. no.	Locality	Ash	Mn	SiO_2	SO_3	Al_2O_3 and Fe_2O_3	CaO	MgO	Na_2O	P_2O_5	K_2O	N
5302	Akron	9.66	.0056	3.21	1.20	2.04	2.390	.311	—	.299	.1594	3.42
5303	"	14.58	.0099	6.18	.97	2.91	2.870	.331	—	.345	.3117	3.24
5304	"	9.84	.0220	4.05	1.03	2.19	3.580	.361	—	.342	.1531	3.38
5305	"	14.38	.0332	5.26	1.03	2.44	3.650	.297	—	.469	.2956	3.10
5306	"	11.65	.0515	4.01	.88	2.65	2.800	.345	—	.337	.1860	3.18
14460	Lodi	—	—	—	—	5.15	4.529	.570	2.366	.506	.4753	—
14461	"	—	—	—	—	4.24	2.570	.420	3.373	.342	.3239	—
14462	"	—	—	—	—	5.62	4.060	.650	2.040	.374	.3569	—
14463	"	—	—	—	—	11.15	2.210	.660	1.944	.256	.9835	—
14464	"	—	—	—	—	4.08	3.050	.630	1.066	.373	.3376	—
14465	"	—	—	—	—	4.18	2.340	.420	2.018	.429	.3445	—
14162	McGuffey	—	—	—	—	—	3.585	—	—	.370	.4720	2.48

The water from peat soils is relatively clear; in several places of the state it is used occasionally for drinking purposes. The suspended particles impart to it a tinge of color from olive green to brown. Analyses of samples of bog water and bog lake water give the following results:

TABLE III

CHEMICAL ANALYSES OF BOG WATER AND LAKE WATER FROM CRANBERRY ISLAND, BUCKEYE LAKE

Constituents in parts per million	Bog water from cranberry-sphagnum association	Bog water from alder-shrub association	Lake water
Nitrogen as albuminoid ammonia ...	10.34	11.48	4.50
Nitrogen as free ammonia..........	15.19	8.24	2.95
Nitrogen as nitrites...............	0.0005	0.0003	0.00000
Nitrogen as nitrates...............	0.20	0.20	0.1000
Chlorin..........................	0.30	1.00	1.00
Required oxygen..................	71.80	70.30	3.70
Alkalinity (as $CaCO_3$).............	30.00	40.00	75.00
Incrustants (as $CaCO_3$)............	74.00	72.00	76.00
Total solids.......................	140.00	160.00	200.00
Loss on ignition...................	100.00	20.00	4.00

The osmotic pressure of these solutions is the same as that of Ohio lakes, the average lowering of the freezing point varying between 0°.005 and 0°.010 when compared with that of distilled water. The acidity of the solutions varies from less than 0.00075 to 0.004 normal acid when titrated with an 0.05 NaOH solution and phenolphthalein.*

The several analyses submitted do not reveal the obvious distinction between successions of vegetation on peat soils and the changes in the chemical character of the peat. The fact that certain plant associations have an absolutely defined morphological and topographic distinction, and the fact that these contrasts must be attributed to conditions prevailing in the soil, directs special attention to the contrasts between peat soils of the various vegetation units or groups of plants. The following series in TABLE IV is especially suggestive in showing the more typical features of the correlation.

* Livingston, B. E. The physiological properties of bog water. Bot. Gaz. **39**: 348–355. 1905.

The correlation phenomena between vegetation units in bogs and the character of the peat soil are not in all cases as those given in TABLE IV. There are many exceptions to the rule for reasons

TABLE IV

CORRELATION BETWEEN VEGETATION UNITS IN OHIO BOGS AND CHARACTER OF PEAT SOILS

Vegetation unit Locality	Moisture in air-dried sample.	Volatile matter	Fixed carbon	Ash	Nitrogen	Potash, K_2O	Phosphoric acid P_2O_5	Sulphur	Calorific value: calories
Bog meadow succession. Cranberry-sphagnum association.									
Buckeye Lake, No. 41 . . .	9.23	67.99	24.46	8.45	1.01	0.12	0.03	0.43	4792
Lakeville, Holmes, No. 72	6.96	69.15	25.04	5.81	2.38			0.23	5317
Lakeville, No. 73.	7.14	67.42	24.91	7.67	2.39			0.28	5039
Bog shrub succession. Alder-maple association.									
Buckeye Lake, No. 43 . . .	9.90	61.63	27.11	11.26	2.21	0.12	0.03	0.64	4512
Orrville, No. 44.	9.08	63.24	26.18	10.58	2.45			0.46	4981
Bog forest succession. Tamarack association.									
Canton, No. 76.	8.01	62.03	31.84	6.35	3.39			0.33	4912
Fox Lake, No. 78.	8.99	54.46	25.02	20.52	2.41	0.15	0.28	0.89	4375
Mesophytic forest succession. Maple-ash-elm association.									
Mantua Bog, No. 47	10.40	56.33	26.16	17.51	2.46	0.19	0.42	0.86	4550
Bradley Pond, No. 51 . . .	10.11	60.09	27.96	11.95	2.24	0.27	0.19	0.29	4856
Copley Bog, No. 59	11.35	56.85	31.87	11.28	2.72			0.89	4923

that will be stated below. On the whole, however, the results may be summarized in the following well-defined relations:

1. In color Ohio peat ranges from a greenish and grayish brown, due to the presence of clay and marl, through various shades of brown to an almost black variety. In texture peat varies from a loosely compacted fibrous heterogeneous meshwork of plant debris to the fiberless, homogeneous variety.

2. The physical water content of peat is higher in the coarser fibrous substratum of the bog meadow association. The mat, when adjoining open water, adjusts itself easily to changes in the water level of the basin. With the disintegration of the plant tissues the water-holding capacity of peat is higher. The concentration of the peat solutions is very low, varying in parts per million

between 40 and 260 parts of total solids. The osmotic pressure and the acidity of the soil solutions differ but slightly between the various grades of peat soil.

3. Reducing processes in peat soils, judged by methylene blue or a one per cent starch-iodid solution, increase from any marginal point of a peat-depositing lake to the bog meadow association and decrease as the deciduous forest association is approached.

4. The nature of the changes which have taken place in the transformation of vegetable debris into peat is only partly understood. The principal changes are a relative loss in oxygen and hydrogen and a progressive increase in carbon and nitrogen. This is clearly shown in passing from the fibrous peat substratum of bog meadows to the structureless peat occupied by bog forests and deciduous trees.

5. In poorly decomposed peat the percentage of volatile combustible material is high, the percentage of fixed carbon, of nitrogen and ash is low. In well decayed peat the reverse is true.

6. The higher ash content in peat from bog shrub and bog forest associations is believed to be due largely to windblown silt; a bog meadow association interferes less with wind work than the timbered area of a deposit.*

7. Peat contains potash and phosphoric acid in comparatively inconsiderable quantities, only a fraction of one per cent, whereas the percentage of calcium and nitrogen is very high, varying from one to almost four per cent. The capabilities of a soil for crop production are usually judged from the study of the chemical character of the soil, and soils markedly deficient in phosphates, potash, and other salts, are looked upon as barren and sterile. Maintenance of fertility is connected with abundance of these constituents. In peat soils, it seems, the essential mineral salts of the agricultural tripod play only minor rôles for protoplasmic activities and in the growth and ripening of bog plants.

8. More systematic investigations from the standpoint of agricultural chemistry have shown that the number of possible inorganic nitrogenous substances, the quantity of nitrites, nitrates, and ammonia is quite small, ranging from a few thousandths to a few hundredths of one per cent. Practically all the nitrogen contained is, therefore, of organic nature.

* Beyer, S. W. Peat deposits in Iowa. Iowa Geol. Sur. **19**: 698. 1908.

9. Only a small amount of nitrogenous bodies can be extracted from peat by means of water. The relatively low free ammonia and the large amount of oxygen consumed indicate that the organic matter is not in an advanced state of decomposition.

10. The solubility of a coarsely fibrous peat is less than that of peat in a finer state of division and more advanced stage of disintegration. This condition seems to point to the fact that the organic compounds arise mainly through the action of microorganisms. Compounds associated with the decomposition products of proteids by mineral acids, are here practically out of the question.

11. Little is known as to the chemical constitution of peat and of the transition and decomposition products of proteids and carbohydrates arising in peat soils. Biochemical technique has not permitted, as yet, the analysis or the preparation of isolated peat soil constituents of comparative purity. They are undoubtedly of access for chemical investigation and isolation. Known methods of investigation of proteids have been applied in the study of the decomposition products of organic compounds in soils.

Schreiner and Schorey,* Jodidi,† and Robinson‡ have more recently isolated and identified a number of these bodies. In peat soils, however, the compounds are present in small amounts, the number of transition products is undoubtedly larger, and their effects upon living plants is as yet unknown. It is difficult to understand how a substance present in peat soils or in bog water in such minute concentration that for ordinary chemical analysis its influence is negligible, may nevertheless exert a profound effect upon the growth of plants. It is not necessary to assume that this distinctly disproportionate effect is produced by external chemical action, by enzymes, or by biological metabolic products. Peat is a heterogeneous system of substances, and its variable composition renders it difficult to determine what substances are injurious and what substances can actually be absorbed and

* Schreiner, O., and Schorey, E. C. Chemical nature of soil organic matter. U. S. Dept. Agr. Bur. Soils Bull. 74. 1910.

† Jodidi, S. L. Organic nitrogenous compounds in peat soils. Michigan Agr. Coll. Exp. Sta. Tech. Bull. 4. 1909.

‡ Robinson, C. S. Organic nitrogenous compounds in peat soils. II. Michigan Agr. Coll. Exp. Sta. Tech. Bull. 7. 1911.

assimilated by plants. The presence of one substance or the concentration of another constituent as determined by quantitative analysis may have only an apparent relation but not necessarily a causal value. This might be for the reason that the substances are differently distributed on account of differences in solubility or oxidation, are absent in one phase of the decomposition process because of differences in the bacterial flora at work in different layers, or vary greatly with reference to the diosmotic properties of the absorbing organs of plants. Humus has long been recognized as a very important factor in soil fertility, and yet almost all the difficulties in any special problem with humus or peat arise in the lack of knowledge of the chemical nature and the effects on plant life of the various organic compounds resulting from weathering processes and from the activity of microorganisms. The complexity of the problem emphasizes the need of physiological studies. The bacteriological-chemical and the physiological analyses deserve on that account a closer consideration. The writer's method of determining the transformation products in various media inoculated with bog bacteria should possess the exactness and reliability necessary for the solution of this problem. The determination of these bodies by chemical means alone will be only in part of value for investigations in ecology.

Numerous problems of experimentation have arisen quite apart from the main question itself.

It would be interesting to determine the water requirement of bog plants for a growing period and to compile the results on a basis of the water needed for one part of ash yielded. Data on the specific differences in the ratio, i. e., on the water requirements of bog plants and the percentage of ash in herbs, shrubs, and trees covering peaty basins, are not at hand. The analyses reported by C. S. Sargent in the ninth Census of the forest trees of North America give the percentages for some of the trees common to bogs. The data are interesting in showing that the majority of trees frequenting bogs have a percentage of ash less than 0.5, and only a few of the deciduous species occurring on Ohio peat deposits have a percentage of ash as high as 1.5. Comparisons of the quantities of mineral salts contained in peat deposits, differing so widely in

ash constituents from land soils, point also to the fact that differences in mineral components are trifling as compared with the biological processes in the substratum and the differences in the available water.

It remains to be ascertained to what extent the absence of any mineral salt may lead to the unbalanced condition which induces the general pathological effects upon agricultural plants, and whether any one of the salts employed in fertilizers may in part or entirely counteract the injurious effects of peat and humus soils. Plant physiological and particularly agricultural literature contains numerous references to the rôle of mineral salts as nutriments. It must be candidly admitted, that the effects of the various mineral salts produced upon the plant or the cell are far more easily formulated than proved and that a satisfactory interpretation is not possible as yet. It is now known that in the preparation of mineral solutions for plants a certain ratio of the different salts is required. It would be of special interest to note in some detail the relation of potassium and calcium compounds, and the suitable concentrations required to counteract the toxicity of the deleterious bodies in peat soils. The fact that water and salts are as a general rule taken up in a different ratio, differing also according to the species of plants used as an indicator, shows that the relation in balanced solutions affects and is determined primarily by the diosmotic properties of the protoplasmic membrane and its accommodatory processes. The direct effect of mineral salts on the protoplasmic membrane is undoubtedly of greater importance than their supposedly special nutrient value. Tolerance and resistance of plants to physiologically deleterious substances, it may be added, is not one of osmotic relations to bog water, nor is the absorption of water a function of it. A study of the magnitude of the internal osmotic pressure occurring in the roots and in the foliage of bog plants as related to bog conditions has not been carried very far as yet. Wheat plants growing in bog soils do not, however, show more than the usual pressure* isotonic with a 0.3 normal solution of potassium nitrate.

Elsewhere (Bot. Gaz. **49**: 325–339. 1910; and **52**: 1–33. 1911) the writer has shown that contrary to the position taken by

* Fitting, H. Die Wasserversorgung und die osmotischen Druckverhältnisse der Wüstenpflanzen. Zeits. Bot. **3**: 209–275. 1911.

several investigators, peat soils contain bacteria inducing diastatic, inverting, proteolytic, cytohydrolytic, and reducing actions during the digestion of the plant debris in the upper layer of the peat substratum. A marked interdependence was shown to exist between the organisms; and the fact that many organisms are obligate saprophytes capable of growing only on a substratum similar in composition to the character of the respective plant association, is indicative of a close relation between a specific bacterial flora, the progressive disintegration of organic material, and the successions of vegetation in bogs and peat deposits. The characteristic xerophily of ancient* and modern bogs the writer attributes to the edaphic adversities encountered rather than to climatic differences. Though the biological processes in the soil thus appear to be more essential than the quantity of mineral components, there yet remains the question how far microorganisms are active in the change of vegetable matter to peat and lignite, and in the formation of gases and of coal. To what extent is the cooperation either essential, useful, or dangerous in the formation and character of organic compounds available for assimilation? What are the factors affecting and limiting the decomposition of organic matter?

What is the nutritive value of the different carbon and nitrogen compounds arising through the activity of microorganisms? Toxic substances possess an unlike physiological value to different plants and hence it is but one step further to raise the question of the comparative nutrient value of these organic compounds.† More recent experiments with isolated bog bacteria show very clearly the ability of a number of the organisms to increase the amount of assimilable compounds in peat soils. The transpiration values of these cultures for wheat plants lie 200 per cent above that of the control. The fact that to many plants bog toxins are injurious at one concentration but not at another, and that further dilution carries with it a corresponding intensification in

* Dachnowski, A. The problem of xeromorphy in the vegetation of the Carboniferous Period. Am. Jour. Sci. IV. **32**: 33–39. 1911.

† Haskins, H. D. The utilization of peat in agriculture. Massachusetts Agr. Exp. Sta. Rep. **1909**[2]: 39–45. 1909.

Lipman, F. G. Report of the Soil Chemist and Bacteriologist of the New Jersey Agr. Exp. Sta. 188–195. 1910.

growth rate, shows the inefficiency of the usual analytical methods of the organic chemist. Neither the properties, the chemical formula, nor their effect upon transpiration, alone afford an indication of their physiological importance. In addition new analyses of peat, wood, and of bog plants from various zones with reference especially to the ratio between the carbon and nitrogen content, are much to be desired. A study of the relative toxicity of the substratum is not independent from a study of the energy needs of the organism. Both are equally important and must be approached from the point of view of the possible absorption and transformation of the compounds or their neutralization into insoluble, impermeable compounds, and the specific structural and functional peculiarities in plants enabling the change.

Aside from the nutritive inequalities of organic peat soil constituents it is worth while to study more closely the various structural modifications that appear in plants indigenous to the habitat, in the less fit invading plants, and in those which survive. In another paper the writer has shown that the phenomena of absorption and tolerance of plants in bogs deal with consideration of the permeability of the absorbing protoplasmic membrane, its power of endurance and its ability either to absorb and assimilate or to transform injurious bodies into impermeable compounds. The form of invading plants is frequently altered, as is shown by dwarfing, the reduction of number and size of leaves, the loss of buds and branches, and the rapid aging of the plants. This indicates the extent to which the various functional mechanisms involved, such as absorption, conduction, and growth, are interrelated and coordinated. Every green plant is undoubtedly able to a certain extent, to assimilate nitrogenous and other organic compounds. Plants that grow preferably on humus and peat soils must have special absorptive powers, but little is known, as yet, to what extent the roots themselves exert a direct solvent action, enzymatic or otherwise, in rendering the peat available for assimilation, and how far fungal mycorhiza, which form symbiotic unions, are of importance.

The possible scope of this study has been barely indicated.

BOTANICAL LABORATORY,
OHIO STATE UNIVERSITY.